Modeling Surface and Subsurface Hydrologic Interactions in the Biscayne Bay Coastal Wetlands

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Abstract

Restoration of the South Florida ecosystem is a major undertaking for the U.S. Army Corps of Engineers and the South Florida Water Management District in the federally approved Comprehensive Environmental Restoration Plan (CERP). The Biscayne Bay Coastal Wetlands (BBCW) Project is one component of the more than 60 restoration plans and has a goal to restore the coastal wetlands area in Central and South Biscayne Bay along its western shoreline. In the existing condition, fresh water plumes emanating from the mouths of canals and well-defined ditches can create local freshening of Biscayne Bay that can be harmful to sea grasses and the ecology of Biscayne Bay. In contrast to these well-defined surface features, shallow water wetlands can diffuse and moderate the introduction of fresh water into Biscayne Bay. Using wetlands to recharge fresh water into the groundwater system can be useful to minimize fresh water plumes extending into Biscayne Bay and to help minimize and/or impede saltwater intrusion.

This paper describes a preliminary validation problem that simulates 2-D flow simulation in shallow spreader swales connecting to the wetlands. The flow simulation was conducted using the Department of Defense Groundwater Modeling System (GMS) and the numerical model WASH123D. WASH123D is a multi-dimensional model that fully couples the surface and subsurface flow equations with design level computational accuracy. The multi-dimensional approach models

groundwater in 3-D, overland flow in 2-D, and canals and hydraulic structures in 1-D. Simulations will be presented that demonstrate how shallow spreader swales can help recharge surface waters into the groundwater and thus reduce related adverse impacts and help restore desirable ecologic balance to Biscayne Bay and adjacent upland areas.

Background

Biscayne Bay relies on substantial amounts of distributed freshwater to sustain its estuarine ecosystem. During the past century, field observations suggest that the delivery of freshwater to Biscayne Bay has changed from overland sheet flow to one controlled by releases of surface water at the mouth of canals. The existing freshwater discharges to the bay are stressful to fish and benthic invertebrates in the bay near the canal outlets. Current restoration efforts in southern Florida are examining alternative water management plans that could change the quantity and the timing (Q & T) of freshwater delivery to the bay by restoring coastal wetlands along its western shoreline of Biscayne Bay. One scenario to address this effort is to create a spreader swale system to redistribute available surface water entering the area from the regional canal system. The spreader swale system would consist of a delivery canal and shallow swales where water flows across the swale banks and becomes a more natural overland flow through existing coastal wetlands.

Numerical modeling approach

Figure 1 shows one component of a proposed restoration plan for the Biscayne Bay coastal area. The restoration plan will involve 1-D canal, 2-D overland, and 3-D subsurface flow. Three important aspects that must be modeled correctly are the 1-D canal flow and 3-D subsurface interactions, the 2-D overland flow in the shallow swales, and 2-D overland flow & 3-D subsurface flow interactions. The 2-D overland flow to a shallow swale is investigated in this paper.

Description of WASH123D

The new version of WASH123D [Yeh, et al., 1998] is being used to model the BBCW and interactions between surface water and groundwater. WASH123D is a physics-based, unstructured finite element model. The model is designed to simulate flow, chemical, and sediment transport in watershed systems. WASH123D includes six modules for simulating 1) 3-D subsurface flow and transport, 2) 2-D overland flow and transport, 3) 1-D river/stream flow and transport, 4) coupled 2-D overland, 3-D subsurface flow and transport, 5) coupled 1-D river/stream, 2-D overland flow and transport, and 6) coupled 1-D river/stream, 2-D overland and 3-D subsurface flow and transport.

The special features of WASH123D include physics-based global and internal boundary conditions that most other models do not have. These boundary conditions include river-subsurface interactions, river-overland interactions, and overland-subsurface interactions. These features are designed to compute the flux interchanges between two media interfaces. The model also has a capability of simulating variable-density in subsurface flow. The south Dade county primary and secondary canal systems are included in the model.

Three options are provided for modeling flow in the river/stream network and overland regime: the kinematic wave approach, diffusive wave approach, and dynamic wave approach. The diffusive/kinematic wave approach was numerically approximated with the Lagrangian method. The dynamic wave approach was first mathematically transformed into characteristic wave equations, and then numerically solved with the Lagrangian–Eulerian method. In subsurface flow, Richard's equation is used to simulate flow through saturated-unsaturated porous media.

In the transport module for 1-D river/stream network, 2-D overland regime, and 3-D subsurface media, both contaminant and sediment transport are provided to simulate the reactive and non-reactive chemical species. Dissolved chemicals are the only chemicals that may appear in both surface and subsurface systems. They may enter the subsurface system from the surface system through infiltration or from subsurface to surface through seepages.

The Department of Defense Groundwater Modeling System (GMS) [http://chl.wes.army.mil/software/gms/] was used to generate the computational mesh, assign boundary conditions, and plot the numerical results.

Flow simulation in shallow spreader swales and wetlands

This validation problem is designed to evaluate if the code can simulate water flows through the shallow spreader swales that connect to wetland areas similar to the Biscayne Bay coastal area. Figure 2 shows the surface elevation contours of the computational mesh. The mesh consists of channel, spreader swales, and overland area. The channel depth is 0.5 meter. The depth at the both ends of the spreader swale is 0.4 meter. The depth at the center portion is 0.5 meter. The area east of spreader swale bank is designated as wetlands area. A time-dependent stage was applied on the east boundary to let water flow in and out freely (Table 1). A no-flux boundary condition was applied on the north and south boundary sides that served as drainage divides. A time-dependent rainfall (7.0e-06 m/s =1 inch/hour) was applied as a natural source to the overland area (Table 2). Specified head conditions were applied on the west boundary at the channel to bring water into the mesh (Table 3). The Manning's roughness in the overland area is 0.040. The overland flow was characterized by the 2-D diffusion wave equation that was solved using the Lagrangian-Eulerian method. Figure 3 shows the boundary condition configuration used in the model.

The expected model results would show that water flows through the channel into spreader swale and flows through the east bank of the swale into the overland wetlands area. The simulation starts with a dry channel, spreader swale, and dry wetland area. Figures 4 through 7 show the computed water depth contours and velocity vectors at four different time: time=80 seconds, 110 seconds, 140 seconds, and 180 seconds. The velocity vectors are shown in directions of flow and not in scale. The velocity vectors outside of channel and spreader swale are contributed by precipitation runoff. Figure 4 shows water front reaches to the end of channel and the computed velocity patterns follow the natural flow path. Figure 5 shows that water flows into spreader swale and the elevated stage almost reaches the bank of spreader swale. Figure 6 shows that the water front reaches the end of spreader swale and water flows across the bank of the center section of the spreader swale. The flow patterns indicate that the overland flow follows the natural flow path of the terrain. Figure 7 shows that the water flows completely across the banks of spreader swale. The flow patterns indicate that water flows from the channel into the overland area and that the area east of the spreader swale becomes shallow wetlands. The results indicate that the model simulates water flowing from the channel through the shallow spreader swale creating a wetlands area in the adjacent prior dry overland area.

Summary

This validation problem shows the WASH123D code correctly simulates flow in the spreader swales and overland areas. This is one of many validation problems that are being tested to ensure that the modules of WASH123D are functioning properly.

References

Yeh, G.T., Cheng, H. P., Cheng, J. R., Lin, H.C., Martin, W. D. (1998). "A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in Watershed System of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media (WASH123D: Version 1.0)", Technical Report CHL-98-19, July 1998, US Army Corps of Engineers, Waterways Experiment Station, 3900 Hall Ferry Road, Vicksburg, MS 39180-6199, USA.

Table 1. Stage boundary conditions at the east side boundary

Time (seconds)	Stage (meter)
0.0	8.30
900.0	8.40
1200.0	8.43

Table 2. Rainfall used in the 2D overland flow simulation

Time (seconds)	Rainfall (meter/second)
0.0	7.0e-06
120.0	7.0e-06
240.0	3.5e-06
480.0	1.0e-06

1200.0	0.00

Table 3. Specified head boundary in the channel at the west side boundary

Time (seconds)	Specified Head (meter)
0.0	9.00
20.0	9.08
40.0	9.16
60.0	9.24
80.0	9.32
120.0	9.40
140.0	9.48
150.0	9.56
180.0	9.64
210.0	9.72
240.0	9.80
270.0	9.80
300.0	9.72
330.0	9.64
360.0	9.56
1200.0	9.24

Figure 1 Deering Estates Component of restorative plan in the Biscayne Bay coastal areas (Green: proposed swales, Yellow: existing canals)

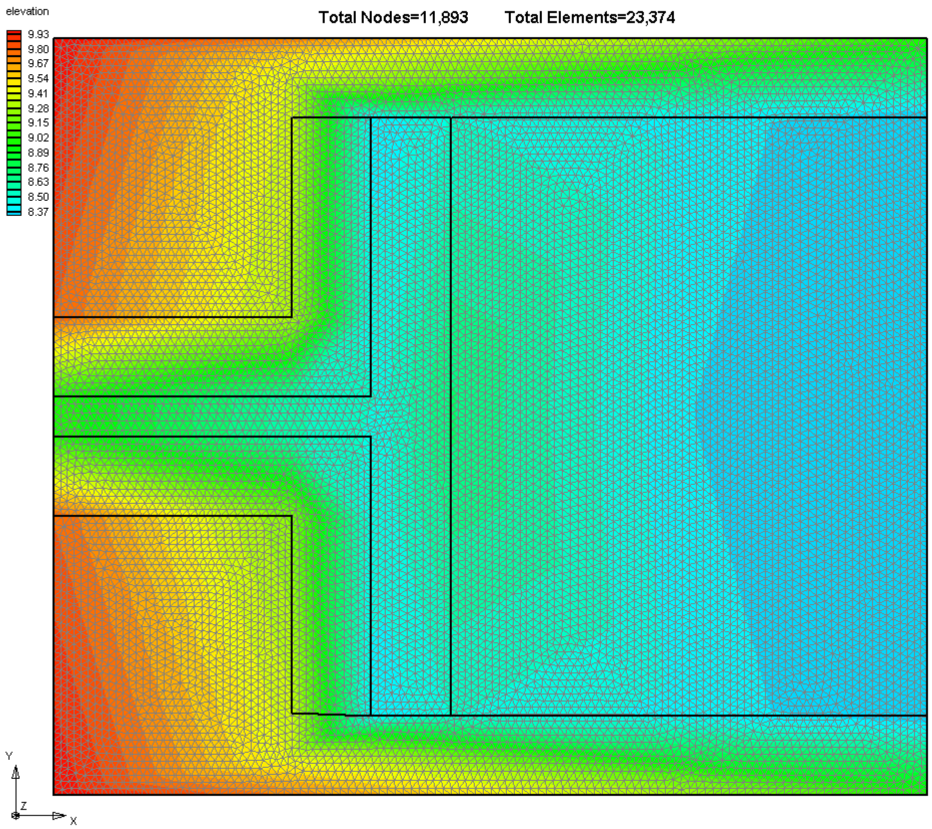

Figure 2. Surface elevation contours of the computational mesh

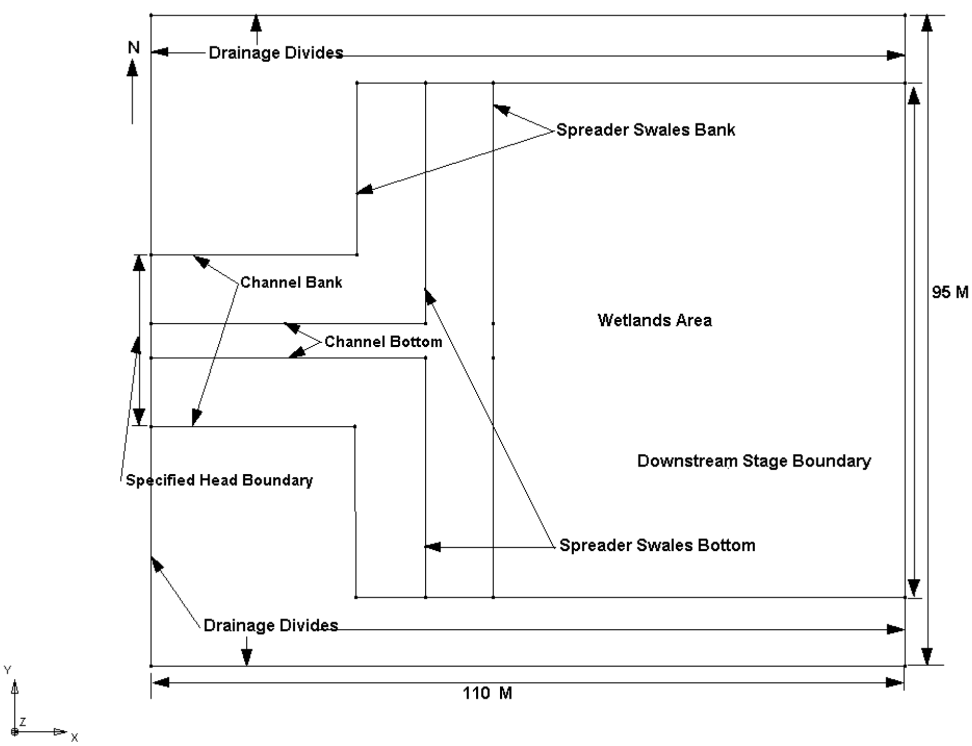

Figure 3. 2-D overland flow boundary condition configuration

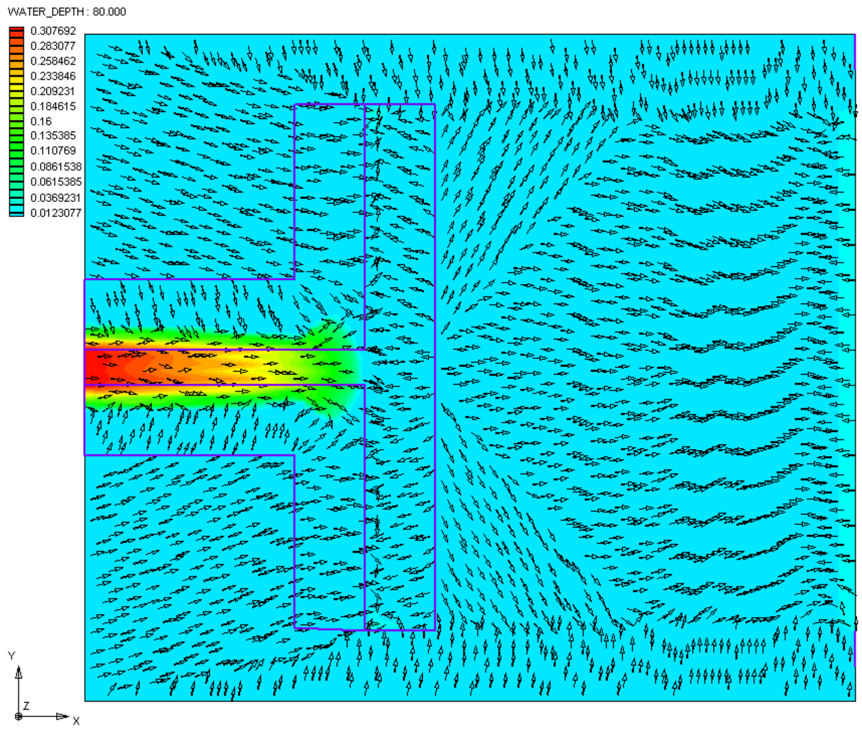

Figure 4. Color shaded contours of computed water depth and velocity vectors at the time=80.0 seconds.

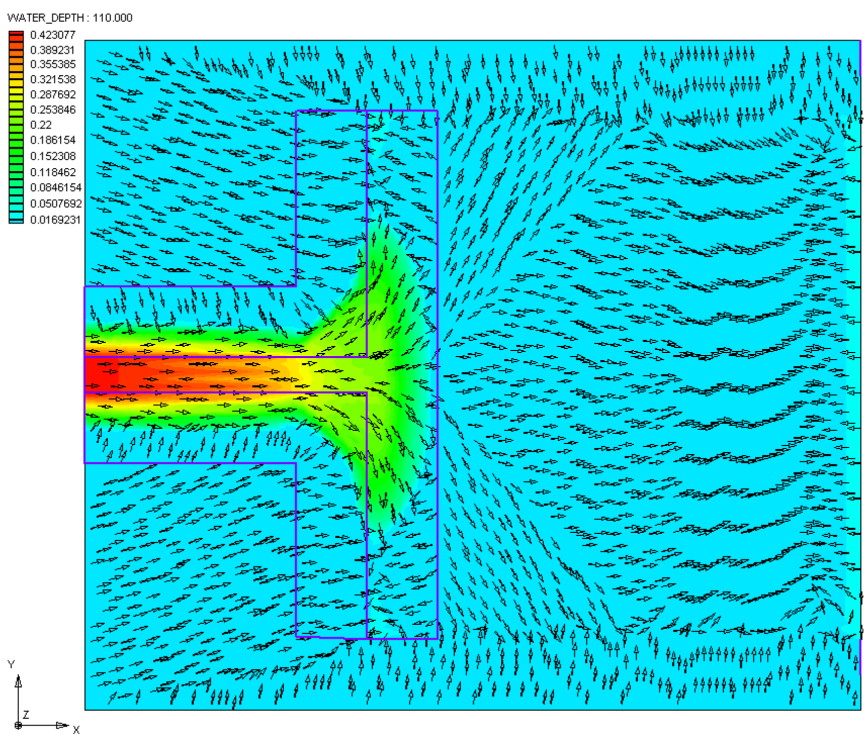

Figure 5. Color shaded contours of computed water depth and velocity vectors at the time=110.0 seconds.

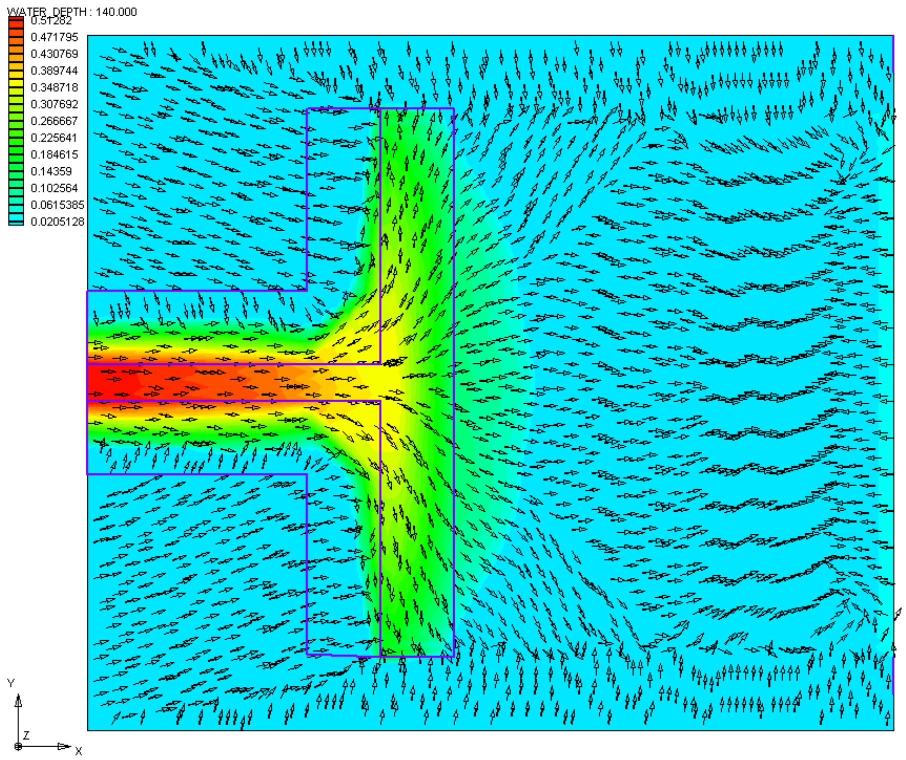

Figure 6. Color shaded contours of computed water depth and velocity vectors at the time=140.0 seconds.

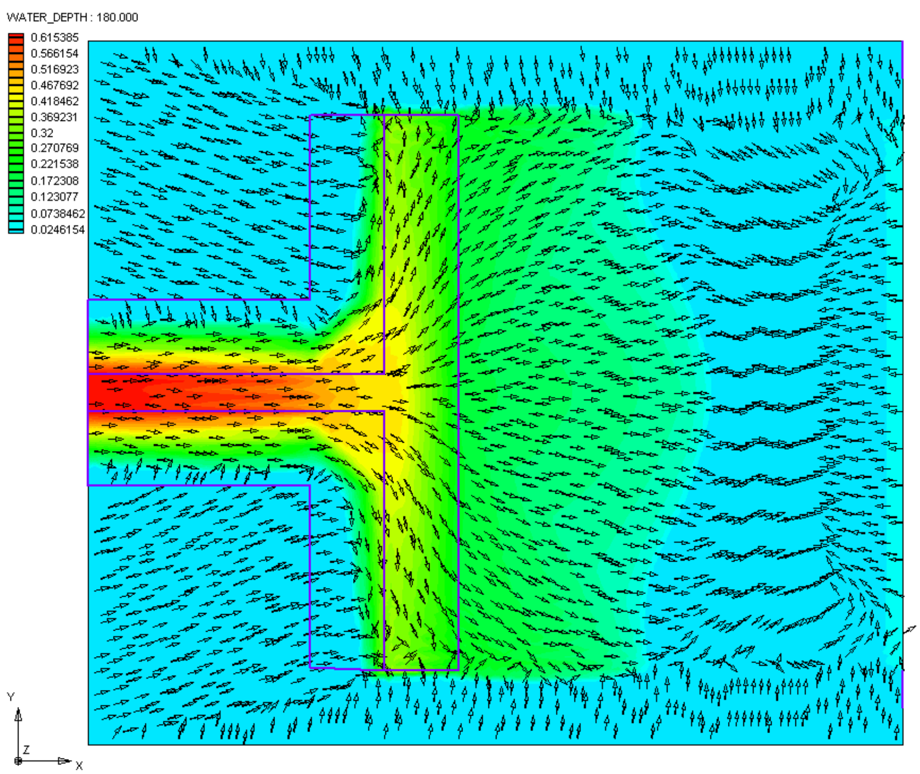

Figure 7. Color shaded contours of computed water depth and velocity vectors at the time=180.0 seconds.